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September 21, 2000

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APPLICATION NUMBER: ***60/152,460***
FILING DATE: ***September 03, 1999***

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A/ PROV

JC644 U.S. PTO 09/03/99

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR A PATENT under 37 CFR 1.53 (b)(2).

Docket Number	1412-4USPR	Type a plus sign (+) inside this box→	+

INVENTOR(s)/APPLICANT(s)

LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
Grudin	Oleg		Montreal, Canada
Gendin	Alexander		Montreal, Canada

JC553 U.S. PTO 60/152460 09/03/99

TITLE OF THE INVENTION *(280 characters max)*

Method for improvement of flowmeter accuracy

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ENCLOSED APPLICATION PARTS *(check all that apply)*

X	Specification	Number of Pages	4	X	Small Entity Statement
X	Drawings	Number of Sheets	2		Other (specify)

METHOD OF PAYMENT *(check one)*

	A check or money order is enclosed to cover the Provisional filing fees	PROVISIONAL FILING FEE AMOUNT ($)	$75.00
X	The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number. 19-5113		

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[X] No

[ ] Yes, the name of the U.S. Government agency and the Government contract number are: ______________________

Respectfully submitted,

SIGNATURE [signature]

Date Sept. 2/99

TYPED or PRINTED NAME James Anglehart

REGISTRATION NO. *(if appropriate)* 38,796

[ ] Additional inventors are being named on separately numbered sheets attached hereto.

PROVISIONAL APPLICATION FILING ONLY

In the United Stat s Patent and Trademark Office

"Express Mail" mailing label number: EH576252816US
Date of Deposit: September 3, 1999

I hereby certify that the attached U.S. Patent Application, informal drawings, transmittal letter, verified statement, declaration and power of attorney, information disclosure statement, and application fee are being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner of Patents, Washington, D.C. 20231.

Randall L. Reed

(Signature)

September 3, 1999

Assistant Commissioner of Patents
Box: Provisional Patent Application
Washington, D.C. 20231

Dear Sir:

Transmitted herewith for filing is the Provisional Patent Application of:

Inventor: Grudin, Oleg and Gendin, Alexander
For: Method for Improvement of Flowmeter Accuracy
Attorney Docket Number: 14112-4USPR

Enclosed are:

1. A Specification with 4 pages.

2. 2 sheets of informal drawings.

3. A Provisional Application for Patent Cover Sheet, signed on September 2, 1999 by James Angelhart Reg. # 38,796. (1 page)

4. A Declaration for Small Entity Status Sheet, signed by Oleg Grudin and Alexander Gendin, on September 2,1999. (1 page)

5. A return receipt post card.

Respectfully submitted,

Date: September 3, 1999

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METHOD FOR IMPROVEMENT OF FLOWMETER ACCURACY.

Background

Typically, flowmeters contain two key functional parts – Gas Flow Receiver (GFR) and differential pressure transducer. The GFR is a tube through which the gas flow to be measured is conducted. The differential pressure generated by a flow resistive element inside the GFR is measured by a differential pressure transducer. Some practical applications, such as spirometry, require that the GFR have an extremely simple shape. This requirement results from the necessity to simplify the GFR cleaning or sterilization, or even the necessity to use cheap disposable GFRs. Analogous requirements may occur in many technical applications where the measured gas flow can be contaminated by liquid or solid particles or water vapor, which may adversely affect the conversion factor of the GFR, and necessitate periodic cleaning of the GFR. This may be relevant in many industrial systems, for example gas handling systems, and gas pipelines.

It was shown that the GFRs with simple shape and non-linear conversion characteristic [(flow)-(differential pressure)] have serious advantages with respect to traditional linear Fleisch- or Lilly-type tubes [US Patent 5038773]. However, the differential pressure which is generated by this type of GFR is a square function of the flow, which results in the following problems.

A requirement to measure flow in a dynamic range of 10^3, say from 15ml/s to 15l/s (spirometry), necessitates the measurement of differential pressure, generated by the GFR, in a dynamic range of $10^6=(10^3)^2$. On the other hand, a limitation of maximal flow impedance of the GFR at about 150Pa·s/l, established by contemporary spirometry standards (American Thoracic Society Standards for Spirometry), restricts the maximal generated back-pressure to (150Pa·s/l)x(15l/s)≈2kPa. Therefore the minimum detectable differential pressure of the pressure transducer should be at the level of several mPa. This requirement, combined with the necessity to operate in a dynamic range of six orders of magnitude is a serious challenge for differential pressure transducers [US Patent 5038773]. The search for methods of improvement of flowmeter resolution at low flows, and hence its accuracy, is of great practical importance. Medical Graphics Corp. proposed a flowmeter containing two differential pressure sensors with an overlapping operating range of six orders of magnitude having a special sensor activated at low flows [US Patent 5038773]. The electronic module of this spirometer has a sophisticated structure including special tools for sensor switching and signal processing.

Contemporary spirometers typically contain analog-to-digital converters (ADC) digitizing analog signals from the transducer for subsequent processing. To provide the required resolution in a wide operating range mentioned above, an ADC with resolution higher than 16-18 bits should be used. Meanwhile, comparatively cheap, simple and widespread 12-bit ADCs are preferable. Therefore the problem of resolving of low flows by the flowmeter with nonlinear GFR arises not only from the restricted sensitivity of differential pressure sensors but also from the limited resolution of the preferred electronic circuitry.

Another problem is also caused by the necessity to detect and process differential pressure signals approximately 1000 times lower than those generated by almost linear Fleisch- or Lilly-type tubes. During flowmeter operation, for example, patient spirometry testing, some vibrations or shocks of the device parts, such as the pneumatic hoses connecting the GFR with differential pressure sensor, may occur. Being negligibly small with respect to differential pressure signals generated by <u>linear</u> GFRs, these parasitic signals may nevertheless be significant compared to useful signals generated by nonlinear GFRs. Interference by spurious signals such as due to vibrations, reduces the accuracy

of the flowmeter. Immunity to these vibrations is considered to be an important feature of the flowmeter especially for compact hand-held versions of the device. Signal filtering techniques to suppress parasitic signals can be used with the following restriction. Requirements on frequency response of the flowmeter specified by relevant regulatory documents (standards, such as the ATS standards) should not be violated as a result of the filtering. For example, spirometry standards define a speed of response required to measure flow parameters of the patient's respiration which should be maintained by any spirometer.

The present invention targets the following problems:

- Improve resolution and hence accuracy of the flowmeter at low flows;
- Improve immunity of the flowmeter to vibrations or shocks of the device and its parts.

Summary of the invention and description of the drawings

To increase resolution at low flows of the flowmeter containing an ADC, the following signal processing is proposed.

Option 1.

1.1) The output analog signal of the differential pressure transducer should have high frequency components at frequencies $f > 1/\Delta t$, where Δt is the ADC sampling rate, where the amplitude of these high-frequency components must exceed one quantization unit of the ADC;

1.2) If the output analog signal of the differential pressure transducer does not have high frequency components at frequencies $f > 1/\Delta t$ with amplitude exceeding one quantization unit of the ADC, then an artificially-generated oscillating signal or noise meeting this criteria should be mixed with the signal prior to digitizing by the ADC;

1.3) The average output signal voltage is calculated by arithmetic averaging of several samples from the output of the ADC, during a time $\tau = N \cdot \Delta t$, where $N > 2$, with resolution better than the quantization unit the ADC;

1.4) The flow corresponding to averaged signal voltage from 1.3) is calculated from the calibration curve of the flowmeter;

Option 2. Output analog signal of the differential pressure transducer, as specified above in 1.1)-1.2), can be processed as follows:

2.1) The flow corresponding to the digitized output signal voltage sample is calculated from the calibration curve of the flowmeter;

2.2) The averaged flow is calculated during time $\tau = N \cdot \Delta t$, where $N > 2$.

3. To suppress parasitic signals due to vibrations or shocks of the flowmeter or its parts, without degrading the frequency response of the device, the output analog signal of the differential pressure transducer, conditioned with high-frequency components as specified in 1.1)-1.2) can be processed as follows:

3.1) The whole operating range of the flowmeter is divided into at least 2 (preferably more) non-overlapping sub-ranges. The averaging times can then be different for each sub-range;

3.2) When flow is measured in accord with 1.3), 1.4) or 2.1) above, the averaging times must monotonically decrease from low-flow sub-range(s) to high-flow sub-range(s).

Fig. 1 shows unfiltered (a) and filtered (b) output signals of the flowmeter at low flows.

Fig.2. shows the reaction of the flowmeter to a flow impulse.

Description of the preferred embodiment

Checking of the invention was performed with the use of a flowmeter containing a nonlinear GFR with a diaphragm-type flow resistive element generating differential pressure as the square of the flow. Mass flow sensor AWM2200, manufactured by Honeywell Inc., was used for differential pressure measurements. Sensor excitation and signal amplification was performed by the circuitry recommended by the manufacturer of the AWM2200 sensor. Reasonable useful frequency bandwidth of the electronic module for the detection of variable flows, specified by the ATS standards, need not be greater than 100-200Hz. To artificially increase the high-frequency noise component of the analog output signal as specified in 1.2), the frequency bandwidth of the electronic module was specially increased up to 10kHz. The increased high-frequency noise component of the analog output signal, determined by white noise of the operational amplifiers of the circuitry, had amplitude of approximately 3mV, equivalent to three quantization units of the ADC. The electronic module contained a typical 12-bit ADC, the AD7890. The digitized signal, with sampling rate Δt =2ms, was transferred to a personal computer for visualization, storage and processing. The minimum detectable flow defined by resolution of the ADC (flow corresponding to +1mV or-1mV, the quantization unit of the ADC) was found to be approximately 50ml/s.

To suppress signals due to vibrations of the hoses and improve the flowmeter resolution at low flows, the following filtering was used. The operating flow range of the flowmeter was divided into four sub-ranges:

$0 \leq$ flow ≤ 0.5 l/s;

0.5 l/s<flow$\leq$1 l/s;

1 l/s<flow$\leq$2 l/s;

2 l/s<flow$\leq$15 l/s.

The averaging time τ was chosen to be 72ms for the first sub-range, 30ms for the second sub-range, 12ms for the third sub-range and 6ms for the fourth sub-range

The effectiveness of the suppression of the vibrations of the pneumatic hoses and improvement of the flowmeter resolution is shown in Fig.1. The filtering allowed increase in flow resolution from 50ml/s to approximately 5ml/s. The suppression factor for vibration-generated signals is approximately 4-5.

While very important at low flows, the described filtering procedure may be redundant at higher flows because of rapid signal rise proportional to the square of flow. For example, rise of flow from 50ml/s to 2 l/s results in signal increase by a factor of 1600 which is more than one order of magnitude higher than parasitic signals due to vibrations. On the other hand, the high frequency response of the flowmeter is required mainly at high flows (spirometry), which would be degraded by a long averaging time τ. Thus, the usage of several sub-ranges with low averaging times, at high flows maintains satisfactory speed of response at medium and high flows. Fig.2 shows reaction of the flowmeter to a flow impulse generated by a 3-liter syringe "SpiroCal" fabricated by Burdick Inc. (Milton, WI, USA). At high flows, the filtered signal (b) has the same shape as the unfiltered one (a). Its fall time is estimated to be less than 10ms. The effect of filtering at low flows can be

recognized by the effective suppression of the oscillating acoustic signal generated by a collision of the piston with the syringe bottom.

The parameters of this filtering method, i.e. number of flow sub-ranges, averaging times and amplitude of the analog signal noise component, can be chosen to optimize the operation of the flowmeter for a particular application. The parameters of the investigated physical process resulting in this choice are required frequency response and flow operating range of the flowmeter and intensity and frequency spectrum of the parasitic signals to be suppressed.

Applicant or Patentee: Oleg Grudin and Alexander Gendin
Application or Patent No.: ________ Atty. Dkt. No.: 14112-4USPR
Filed or Issued: herewith
Title: "Method for improvement of flowmeter accuracy"

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS [(37 CFR 1.9(f) and 1.27 (b)] - INDEPENDENT INVENTOR

As a below named inventor, I hereby declare that I qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees to the Patent and Trademark Office described in:

- ☒ the specification filed herewith with title as listed above.
- ☐ the application identified above.
- ☐ the patent identified above.

I have not assigned, granted, conveyed or licensed and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

- ☒ No such person, concern, or organization exists.
- ☐ Each such person, concern, or organization is listed below.

FULL NAME ________
ADDRESS ________
( ) INDIVIDUAL (x) SMALL BUSINESS CONCERN ( ) NONPROFIT ORGANIZATION

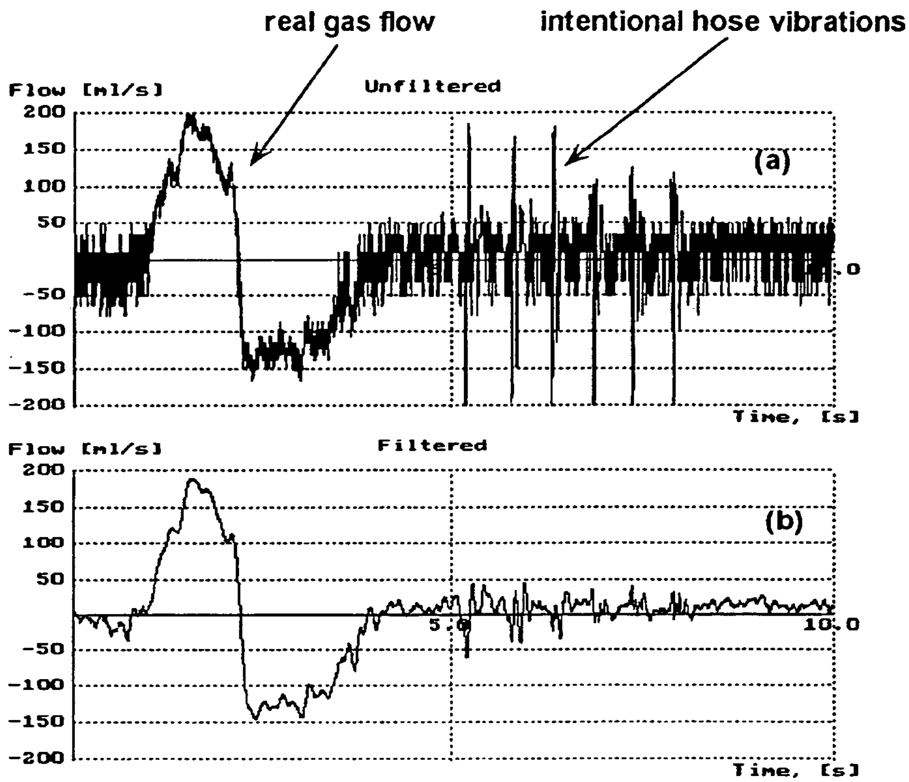
FULL NAME ________
ADDRESS ________
( ) INDIVIDUAL ( ) SMALL BUSINESS CONCERN ( ) NONPROFIT ORGANIZATION

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. [37 CFR 1.27]

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. [37 CFR 1.28(b)]

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF INVENTOR	SIGNATURE OF INVENTOR	DATE
Oleg Grudin	[signature]	02 Sept. 1999
Alexander Gendin	[signature]	2 Sept. 1999


real gas flow
intentional hose vibrations
Flow [ml/s]
Unfiltered
200
150
100
50
-50
-100
-150
-200
(a)
Time, [s]
Flow [ml/s]
Filtered
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150
100
50
5.0
10.0
-50
-100
-150
-200
(b)
Time, [s]

Fig.1.

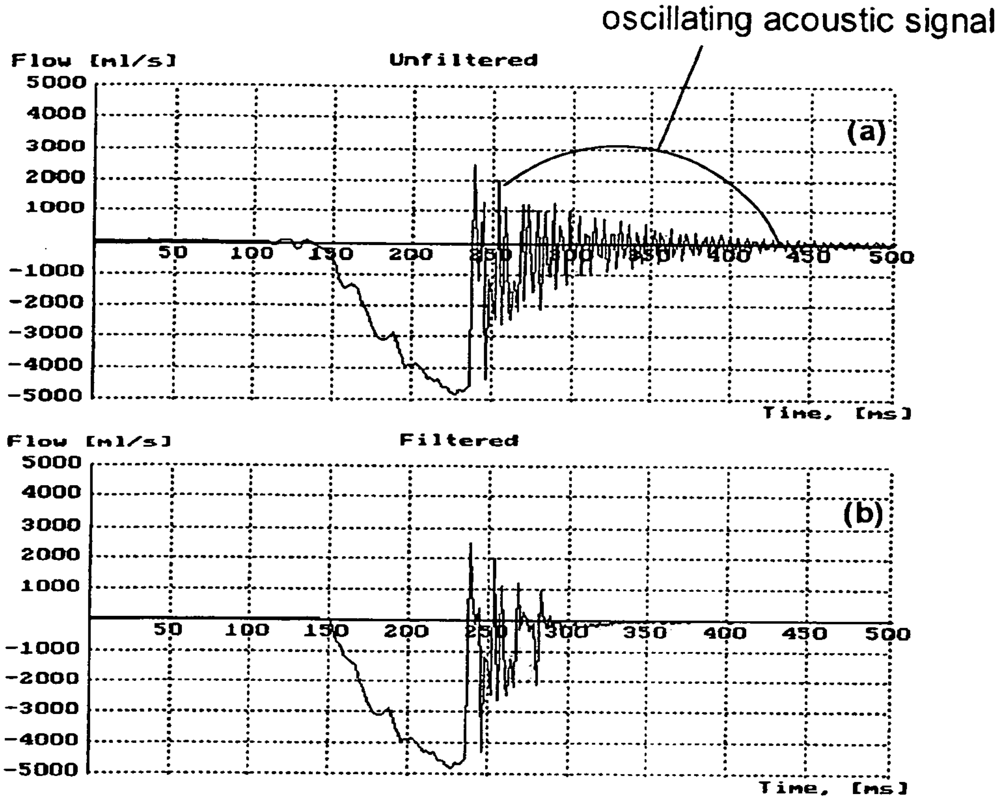
oscillating acoustic signal
Flow [ml/s]
Unfiltered
(a)
5000
4000
3000
2000
1000
-1000
-2000
-3000
-4000
-5000
50
100
150
200
250
300
350
400
450
500
Time, [ms]
Flow [ml/s]
Filtered
(b)
5000
4000
3000
2000
1000
-1000
-2000
-3000
-4000
-5000
50
100
150
200
250
300
350
400
450
500
Time, [ms]

Fig.2.